USING TRAINING TO IMPROVE PERFORMANCE OF INSPECTORS ON THE HANGAR FLOOR

Anand K Gramopadhye[1], Shannon R Bowling[1], Mohammad T Khasawneh[1], Sittichai Kaewkuekool[1], Brian J Melloy[1], Andrew Duchowski[2], Eric Meldin[2], and Nathan Cournia[2]

Advanced Technology Systems Laboratory[1]
Department of Industrial Engineering[1]
Department of Computer Science[2]
Clemson University
Clemson, South Carolina 29634-0920

Abstract. Inspection quality is dependent on the ability of inspectors to weed out non-conforming items. When inspection is visual in nature, humans play a critical role in ensuring inspection quality. Literature has shown training to improve inspection performance. Initially, the paper outlines the basic principles and methodology for inspection training. Following this step, the paper describes how the principles and the methodology were used in designing an inspection-training program for a specific aircraft inspection task. Specifically, the proposed systematic procedure for developing training programs was used for the development of a computer based training program – Automated System of Self Instruction for Specialized Training (ASSIST) – in addition to a simulated virtual reality environment for an aircraft cargo bay.

1. Introduction

Aircraft inspection and maintenance is essential to the safety of air transportation system. Training has been identified as the primary intervention strategy in improving inspection performance. If training is to be successful, we need to provide inspectors with training tools to help enhance their inspection skills. Existing training for inspectors in the aircraft maintenance environment tends to be mostly on-the-job training (OJT). However, this method may not be the best one[a, b] because feedback may be infrequent, unmethodical, and/or delayed. Moreover, in certain instances feedback is economically prohibitive or impractical because of the nature of the task. Because the benefits of feedback in training have been well documented[c], and for other reasons as well, alternatives to OJT are sought.

More importantly, training for improving the visual inspection skills of aircraft inspectors is generally lacking at aircraft repair centers and maintenance facilities even though the application of training knowledge to enhance visual inspection skills has been well documented in the manufacturing industry where training has been shown to improve the performance of both novice and experienced inspectors[c, d]. Visual inspection skills can be taught effectively using representative photographic images showing a wide range of conditions with immediate feedback on the trainee's decision[c, e], a combination of training methods that has also been shown to be superior to OJT alone[f]. A case study presented by Gramopadhye et al.[g] showing how photographic images and feedback were used to develop a computer-based training program for a contact lens inspection task supports the findings of the Latorella et al.[f].

In the domain of visual inspection, the earliest efforts to use computers for off-line inspection training were reported by Czaja and Drury[h]. They used keyboard characters to develop a computer simulation of a visual inspection task. Similar simulations have also been used by other researchers to study inspection performance in a laboratory setting[i]. Since these early efforts, Latorella et al.[f] and Gramopadhye, Drury and Sharit[j] have used low fidelity inspection simulators using computer generated images to develop off-line inspection training programs for inspection tasks. Similarly, Drury and Chi[k] studied human performance using a high fidelity computer simulation of a printed circuit board inspection. Another domain, which has seen the application of advanced technology, is that of inspection of x-rays for medical practice[l]. In summary, most of the work in the application of advanced technology to inspection training has focused on developing low fidelity simulators for running controlled studies in a laboratory environment. Thus, research efforts need to be extended in order to take full advantage of today's computer technology. Moreover, advanced technology has found limited application for inspection training in the aircraft maintenance environment. Presently, most of the applications of computer technology to training have been restricted to the defense industry for complex diagnostic tasks.

Although much has been written about training, very little applies to the acquisition and enhancement of visual inspection skills. Typically articles address either the overall structure of a training program[m] or the technology of training delivery systems[n,o,p,q]. Visual inspection has skill-, rule-, and knowledge-based components and, as such is less amenable to only rule-based diagnostic procedures. In order to evaluate and improve visual inspection performance, the inspection job itself must first be understood. A detailed task analysis is the first step in training[r]. Only when the task is understood can the trainee be evaluated, to determine what training is required to bring the trainee to a high level of performance. Inspection tasks can be classified into two categories, manual tasks and cognitive tasks. Manual tasks consist of initiate, access and respond, while cognitive tasks refer to the search and decision making aspect of the inspection process. Training for manual or procedural tasks is relatively straightforward[s], whereas training for cognitive tasks is not as straightforward or well known.

If we are to have human inspectors as part of the inspection process for the foreseeable future, it is critical that we identify various intervention strategies to improve their performance. Literature on inspection covers various strategies to improve inspection performance, these range from workplace design, design of lighting environment[t] to job aids. Training has been shown to be a potentially powerful technique for improving inspection performance[c]. Large and consistent individual and group differences have been found between inspectors in a variety of domains[u]. Both search[v] and decision aspects[w] of inspection show that controlled practice improves performance. Experience in inspection also affects inspection performance[x]. However, experience in inspection is different from training[y]; a training program can make substantial improvements, bringing novices to a performance level beyond that of experienced workers in days rather than months or years. The following paragraphs describe a systematic approach for developing an inspection training program, which was used for the development of specialized training programs for aircraft inspection tasks.

2. A Systematic Approach to the Development of an Inspection Training

Researchers and training practitioners have proposed various methodologies for developing training programs[b,w,r]. Figure 1, adapted from Gramopadhye, Drury and Prabhu[z], outlines a step-by-step methodology to design an inspection training program. The figure shows the organizational inputs and objectives/goals at each step of the training program development methodology. Having defined the training program development methodology, any training program consists of the training content, training methods and the training delivery system. The various steps in the methodology are covered in greater detail in the following sections.

2.1 Task Analysis

To evaluate and improve visual inspection performance, we first need to understand and describe the task in detail. The first step in understanding a task is to perform a detailed task analysis[aa,r,ab]. Task analysis helps in isolating the critical characteristics of the tasks by delineating the task in an orderly way, at different levels of detail[w]. It is only when we understand the different elements of the task that we can evaluate which elements are trainable and determine what type of training is needed to bring the inspectors to a superior level of performance. Different approaches to task analysis can be used; the two most popular ones are hierarchical task analysis[aa] and sequential task analysis[ac]. In a hierarchical task analysis, the tasks are broken down into different levels of detail, and at each level the training methods required to improve specific aspects of the task can be identified. In a sequential task analysis, the inspector's task is represented as a series of operations required to perform the inspection task.

2.2 Training Group Analysis

The next step involves identifying the trainers who will be responsible for conducting the study and the trainees (the population of inspectors) who will be involved in the study. This step also involves conducting an analysis of all the relevant characteristics of all the inspectors who will be participating in the program, which includes demographics data and the trainees' knowledge and/or skills relevant to the inspection task. A second type of useful information relevant to the design of the training program is the trainees' perception as to what is important to the job, trainees' skill deficiencies, and other problems[b].

2.3 Training Goals

If training is to be successful, the goals that have to be achieved by training need to be established. Any inspection system must achieve two goals: speed and accuracy[d]. Accuracy means that the non-conformity must be detected and the item must be correctly classified. Speed means the task must be performed in a timely manner. At the inspector's level these two goals can be expected to be inversely related[ad], i.e., the accuracy will generally decrease as the speed increases. Thus, there could exist speed-accuracy tradeoffs in inspection, and the training objective must be sensitive to these tradeoffs. For example, products used for military or aircraft purposes require high quality, so the weight for accuracy for these products should be high. On the other hand, commodity products may require high volume production; therefore, the weight of speed should be emphasized. The weight of a false alarm should be emphasized for expensive products while the weight of misses should be higher if the failure cost to the final system is high. The Human Factors analyst at this stage needs to interact with the Quality Control Managers and Inspection Supervisors to clearly establish the goals of the inspection system so that they are transparent to other participants (e.g., manufacturing engineers, supervisors, etc) within the system. It is important that this activity clearly define the characteristics of a conforming and a non-conforming product[w].

2.4 Development of the Training Program

This step involves defining the overall training program. The task analysis, along with the trainee analysis, can be used to compare the knowledge and skills required by the task and that possessed by the trainees to determine gaps that need to be addressed by the training program. Patrick[ae] identified the training content, training methods and trainee as the important constituents of the training program. Drury[ad] includes the training delivery system as another component of the training program. Although a considerable amount has been written about designing training systems[ae,b] very little focuses directly on enhancement of visual inspection skills. Embrey[w] states that for any training program to be effective, it should address the following three issues: attitude of the trainee at work, knowledge required to perform the job, and the specific skills required to perform the task. Specific training methods which can be used for inspection training[af,z] are described below:

1. Pre-training: Pre-training provides the trainee with information concerning the objectives and scope of the training program. During pre-training, pretests can be used to measure (a) the level at which trainees are entering the program and (b) cognitive or perceptual abilities that can later be used to gauge training performance/progress. Advanced organizers or overviews, which are designed to provide the trainee with the basics needed to start the training program, have been found to be useful. The elaboration theory of instruction[ag] proposes that training should be imparted in a top-down manner wherein a general level is taught first before proceeding to specifics. Overviews can fulfill this objective by giving the trainee an introduction to the training program and facilitating assimilation of new material.
2. Feedback: A trainee needs rapid, accurate feedback in order to know whether a non-conformity was classified correctly or a search pattern was effective. Feedback with knowledge of results, coupled with some attempt of performing the task, provides a universal method of improving task performance[c]. This applies to learning facts, concepts, procedures, problem solving, cognitive strategies and motor skills[ah,ai]. The training program should start with rapid feedback which should be gradually delayed until the "operational level" is reached. Providing regular feedback beyond the training session will help to keep the inspector calibrated[aj]. Gramopadhye et al.[z] classify feedback as performance and process feedback. Performance feedback on inspection typically consists of information on search times, search errors and decision errors. Process feedback, on the other hand, informs the trainee about the search process, such as areas missed. Another type of feedback called "cognitive feedback" has emerged from the area of social judgment theory. Cognitive feedback is the information provided to the trainee of some measure of the output of his or her cognitive processes. For inspection tasks, process feedback is the same as cognitive feedback.
3. Active Training: In order to keep the trainee involved and to aid in internalizing the material, an active approach is preferred. In active training, the trainee makes an active response after each piece of new material is presented, e.g., identifying a fault type. Czaja and Drury[h] used an active training approach and demonstrated its effectiveness for a complex inspection task.
4. Progressive Parts Training: Salvendy and Seymour[ak] successfully applied progressive part training methodology to training industrial skills. In the progressive parts methodology, parts of the job are taught to criterion and then successively larger sequences of parts are taught. For example, if a task consists of four elements E1, E2, E3 and E4, then the following would follow:

   - Train E1, E2, E3 and E4 separately to criterion

- Train E1 and E2; E3 and E4 to criterion
- Train E1, E2 and E3 to criterion and E2, E3 and E4 to criterion
- Train the entire task to criterion

This method allows the trainee to understand each element separately as well as the links between the various elements thus representing a higher level of skill. On the other hand, reviews of literature reveal that part task training is not always superior. The choice of whether training should be part or whole task training depends on "cognitive resources" imposed by task elements and the "level of interaction" among individual task elements[b]. Thus, there could be situations in which one type of task training is more appropriate than the other. Naylor and Briggs[al] have postulated that for tasks of relatively high organization or complexity, whole task training should be more efficient than part task training methods.

5. Schema Training: The trainee must be able to generalize the training to new experiences and situations. For example, it is impossible to train the inspector on every site and extent of scratches on a contact lens so that the inspector is able to detect and classify a scratch wherever it occurs. Thus, the inspector will need to develop a "schema" for scratches which will allow a correct response to be made in novel situations. The key to the development of schema is to expose the trainee to controlled variability in training[y].
6. Feedforward Training: It is often necessary to cue the trainee as to what should be perceived. When a novice inspector tries to find non-conforming contact lenses, the indications may not be obvious. The trainee must know what to look for and where to look. Specific techniques within cueing include match-to-sample and delayed match-to-sample[y]. Feedforward information can take different forms such as physical guidance, demonstrations, and verbal guidance. Feedforward should provide the trainee with clear and unambiguous information that can be translated into improved performance.

2.5 Training Delivery System

Having identified the training methods to be used for improving inspection performance, the next step is to identify the specific training delivery system to be used. Training delivery systems can be classified as Classroom Training, On-the-Job Training and Computer-based Training[z]. Gordon[b] goes on to develop a more detailed taxonomy of delivery systems, listing the advantages and disadvantages of each training delivery system. The choice of the specific delivery system depends on various factors, some of which include the nature of the task, the type of knowledge that needs to be transferred, user background and experience, implementation and developmental costs, time available, consequence of errors and flexibility.

2.6 The Establishment of Performance Evaluation Standards

To understand whether the inspector is achieving the goal, the inspector's performance needs to be measured. Also the instructor/organization needs to know if training is successful, so the performance of the inspector needs to be measured against standards for a select set of performance measures. The problem of determining the correct performance measures is not trivial. Sinclair[ac] and Gramopadhye et al.[z] provide lists of performance measures which can be used to evaluate inspector performance . Often a single measure is insufficient and a set of measures has to be used. Typical measures which are used are speed (i.e. search time, stopping time,etc) and accuracy (i.e. number of hits and misses). Finally, a range for acceptable inspector performance has to be established for each of the performance measures.

2.7 Evaluation

A training program needs to be evaluated once it is developed to determine whether the program does indeed fulfill its objectives. The final evaluation of the training program is conducted not only to establish the program's effectiveness but also to determine which parts of the program were successful and which need revision[b]. Such an evaluation should consist of subjective and objective evaluations. For example, a subjective evaluation measures trainees' opinions and attitudes toward the program and the usability of the training program. The objective evaluation uses variables that do not involve human judgement. For example, previously defined criteria measures (missed non-conformities, inspection time, incorrect classification) can be used to determine if the training program is meeting preset goals. Subjective evaluation is best conducted using rating scales, questionnaires, and interviews, while objective evaluation of the training program can be conducted by running a controlled study. The first technique that can be used to facilitate such an objective evaluation is the pre-test/post-test evaluation. In this technique, data is collected on select criteria measures before the training program is administered and after the training program is finished. A second technique to evaluate training effectiveness is to have a control group, a group that does not receive training, and an experimental group, a group that receives training. By comparing the data for both the groups, inferences on the effectiveness of the training program can be drawn. To facilitate the above evaluation, the following methods can be employed to collect data on inspection performance[ad]:

1. Test sample method: In this method a carefully selected sample of conforming and non-conforming items are presented to the inspector, and the performance of inspector is evaluated on the 'test sample.'
2. Reinspection of production: In this method, items are sampled (conforming and non-conforming)from the inspector's regular output and carefully re-inspected. The inspector's performance is assessed by comparing it to the actual state of each item.
3. Known sample in production sequence: In this method, known items or samples are mixed with regular items to be inspected and, after inspection, removed. This method could be viewed as an intermediate one between the test sample method and the reinspection method.

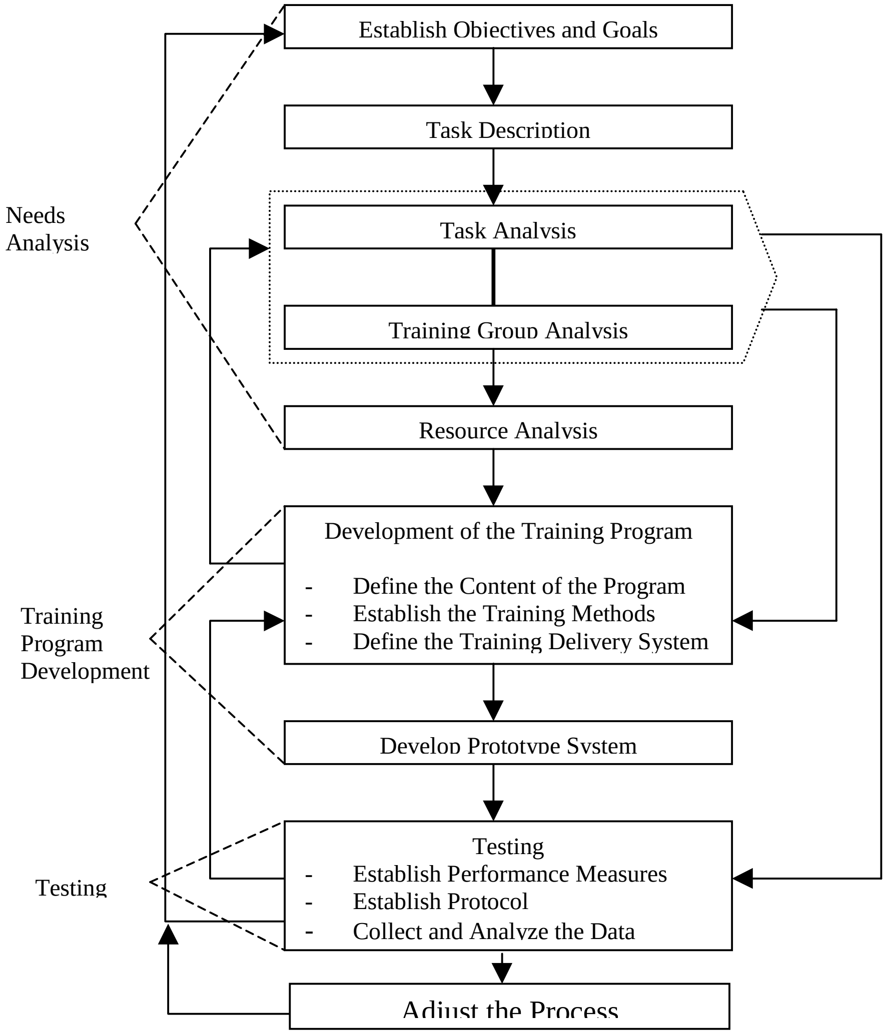
2.8 Implementation

Before the training program is implemented, it should receive approval from all relevant parties. Successful implementation of a training program can take place only by ensuring the participation of those involved with the development of the training program. These parties include the personnel (instructors, supervisors) who are involved in monitoring the training program and the trainees who will be using the training program.

2.9 Iterative Process

Up to this point, the steps in describing the development of a training program have been sequential. However, in reality many of these steps tend to be iterative in nature, wherein the training program designer goes back and fine tunes the training program based on outputs obtained from later stages. The typical iterative loops are shown in Figure 1. In addition to the above reasons for iteration, a designer may have to go through the iteration because of changes in the task environment, in management goals, and in demographics. With the generic methodology for inspection training outlined, the following section describes the use of this methodology in developing a computer-based inspection training program for aircraft inspection.

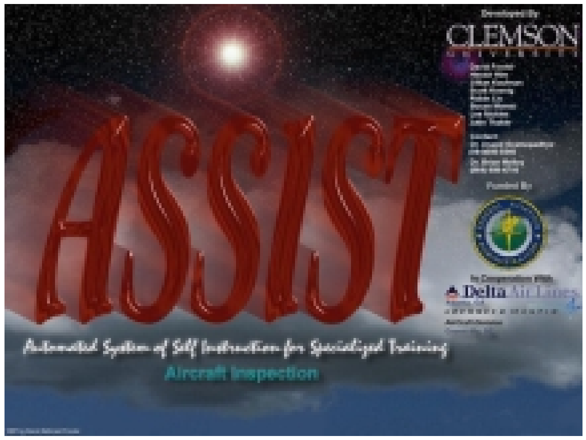
Figure 1. Methodology for Designing the Training Program.



3. Training Programs Development

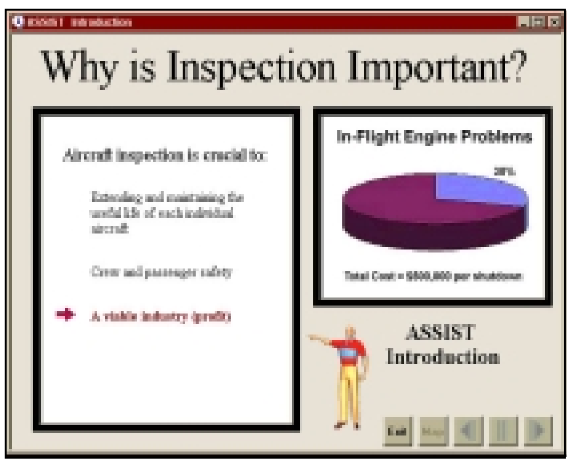
This training program was used to design the first generation of high fidelity simulators. The aforementioned systematic approach for training programs design was used for the development of a computer based training program – Automated System of Self Instruction for Specialized Training (ASSIST). In addition, it was used for developing a virtual reality simulator for an aircraft cargo bay. ASSIST is basically an aircraft inspector training software that consists of three modules: (1) the General Inspection Module, (2) the Inspection Simulation Training Module, and (3) the Instructor's Utilities Module. All system users interact through a user-friendly interface, which capitalizes on graphical user interface technologies and human factors research on information presentation (e.g., color, formatting, layout, etc.), ease of use, and information utilization. A screenshot of the software is shown in figure 2 below and a brief description of the modules follows.

Figure 2. The ASSIST software.



The objective of the general module, which presents information through text, pictures, audio, and video, is to provide the inspectors with an overview of the following sub-modules (Figure 2): (1) role of the inspector, (2) safety, (3) aircraft review, (4) factors affecting inspection, and (5) inspection procedure. The module incorporates multimedia (sound, graphic, text, pictures and video) with interaction opportunities between the user and the computer. Figure 3 shows a sample screen of the general module.

Figure 3. The General Module of ASSIST.



The inspection simulation-training module of the training program provides inspection training on a simulated aircraft inspection task: the aft cargo bin inspection of a Lockheed Martin L-1011-Figure 3). By manipulating the various task complexity factors the instructor can simulate different inspection scenarios. The training module is further divided into four major sub-modules: introduction, search training, decision training and testing. Each sub-module uses computer-generated images of the airframe structure. The simulation module uses actual photographs of the airframe structure with computer-generated defects.

The Instructor Utilities Module is shown in figure 5 and it allows the supervisor/instructor to access the results database, the image database and the inspection parameter modules. The start-up module allows the instructor to select images from the image database and store them in a batch file for use with the inspection simulator, as seen in figure 4.

Figure 4. The Inspection Simulation Training Module of ASSIST.

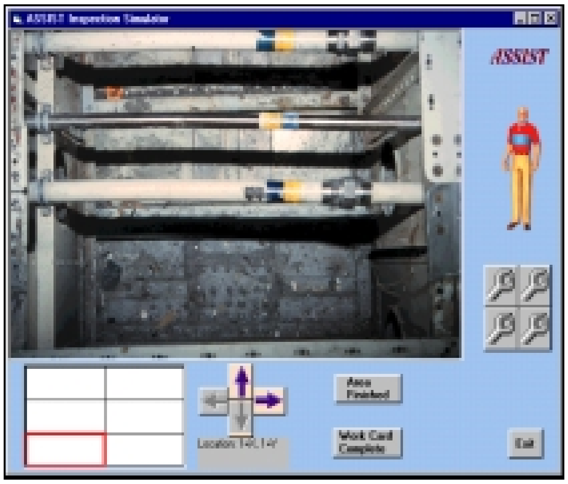
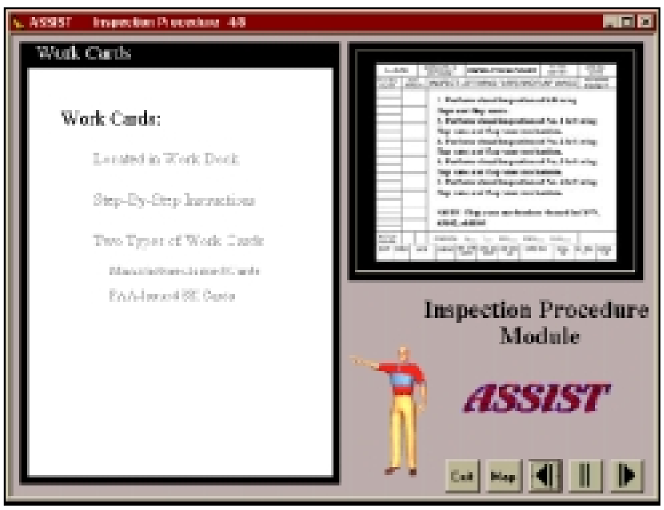


Figure 5. The instructor's Utilities and Startup Module of ASSIST.



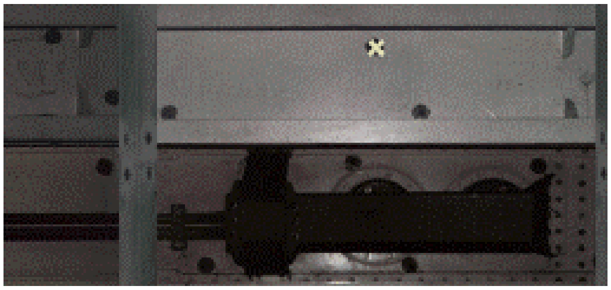
A Virtual Reality (VR) inspection simulator has been developed at the Virtual Reality Eye Tracking (VRET) Laboratory at Clemson University. The VR inspection system is a collaborative extension of recent efforts being pursued at the Advanced Technology Systems Laboratory (ATSL) at Clemson. Previous work at the ATSL focused on the development of a computer based inspection training program—Automated System of Instruction for Specialized Training (ASSIST)[am]. The ASSIST program, developed using a task analytic methodology, features a PC-based inspection simulation of an aircraft cargo bay, where an image of a portion of the airframe is presented to the user for inspection (visual detection of defects). The image is a photo of a section of an aircraft's interior. The user is shown an image selected from a two-dimensional 48 grid of images, and is able to "navigate" left, right, up, and down to view the entire grid, one image at a time. Despite its advantages of being a computer-based inspection training/job-aid tool, the static, two-dimensional layout of the airframe lacks realism. To enhance the fidelity of the inspection system, an immersive, three-dimensional VR system has been developed.

The VR inspection simulator features a binocular eye tracker, built into the system's Head Mounted Display (HMD), which allows the recording of the user's dynamic point of regard within the virtual environment. User gaze directions, as well as head position and orientation are tracked to enable navigation and post-immersive examination of the user's overt spatio-temporal focus of attention while immersed in the environment. The recorded points of regard addresses imprecision and ambiguity of the user's viewpoint in a virtual environment by explicitly providing the 3D location of the user's gaze. The goal of the construction of the virtual environment is to match the appearance of the physical inspection environment, an aircraft cargo bay, shown in Figure 6. The physical environment is a complex three-dimensional cube-like volume, with airframe components (e.g., fuselage ribs) exposed for inspection. A typical visual inspection task of the cargo bay involves carefully walking over the structural elements while searching for surface defects such as corrosion and cracks (among others).

Figure 6. Aircraft cargo bay physical environment.

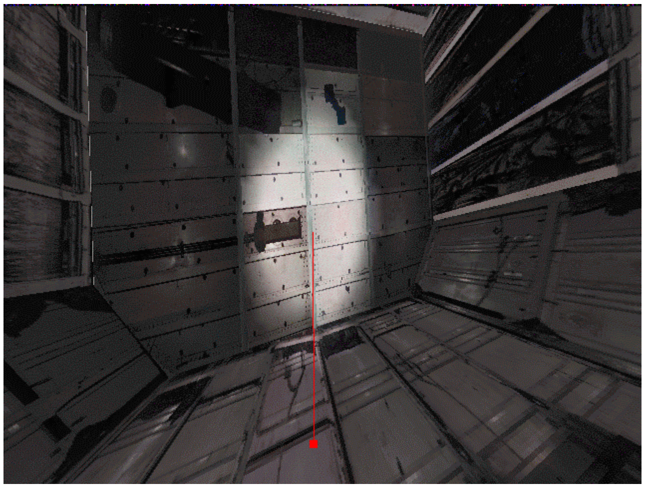
The evolution of the virtual inspection environment began with a straightforward emulation of the two-dimensional ASSIST inspection grid. The rationale for this design was the relatively quick development of a simple texture-mapped grid to provide the user with a more natural representation and navigation of the entire inspection region. Although the VR environment provided advantages over the PC-based system, several problems with its design became evident. An example of defect location in an environment texture map is shown in figure 7.

Figure 7. Example of location of artificially generated defect in an environment texture map.



The main advantage of the VR system is its display of the entire side of the airframe's wall, which provides better context for the user in terms of the location of the individual panels under inspection. The obvious drawbacks of this implementation, however, are the noticeable discrepancies in the appearance of the images (e.g., lighting changes and positional misalignment), and overly simplistic geometry, which is not well suited for a Virtual Reality application. The 2D wall in effect defeats the immersive and natural navigational advantages offered by VR technology. Clearly, to provide an immersive environment, a three-dimensional structure is required. Figure 8 below shows the virtual cargo bay environment that was developed at the VR lab at Clemson University.

Figure 8. The 3D virtual cargo bay environment (with inspecting using a flashlight).



4. DISCUSSION AND CONCLUSIONS

The current research proposed a systematic methodology for designing training program for aircraft inspection. The study further demonstrated that the various delivery systems can be integrated into a single coherent program for inspection training. Moreover, this study showed that an inspection-training program based on sound principles of training design and a well-defined methodology can bring about significant improvements in inspection performance and ultimately inspection quality.

The paper has described research in the area of aviation maintenance and inspection currently underway at Clemson University. Through the development and systematic application of human factors techniques, the research aims at improving the effectiveness and efficiency of aircraft visual inspection. The results of the research effort have been made available to the aviation maintenance community as deliverable products in the form of usable CD-ROMs. It is anticipated that the use of these products would lead to improve airworthiness of the U. S. domestic aircraft fleet. The high degree of control that ASSIST affords will create the opportunity to systematize the training. In addition, there are several other inherent advantages that will serve to alleviate the problems characteristic of OJT: completeness, adaptability, efficiency, integration, certification, and instruction.

Furthermore, we outline how virtual reality technology can be used to realistically simulate the aircraft inspection environment. It further goes on to describe an operational platform for real-time recording of eye movements in Virtual Reality. The platform is based on high-end graphics engines and an electromagnetically tracked, binocular helmet equipped with infrared eye tracking capability. Rendering techniques are relatively simple, relying only on standard (OpenGL) graphics library calls. Tracking routines deliver helmet position and orientation in real-time, which are used directly to provide, updated images to the HMD.

User gaze direction can be tracked in real-time, along with calculated gaze/polygon intersections. This process helps in analyzing recorded gaze intersection points for comparison with stored locations of artificially generated defects in the inspection environment. The use of a VR based inspection environment will enable us to conduct controlled studies off-line, to understand human performance in inspection. Results obtained from these studies will yield interventions, which can be used to improve aircraft inspection performance and ultimately, aviation safety.

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